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CLEANLINESS CONSIDERATIONS FOR THE AFGL INFRARED CELESTIAL SURV--ETC(U)

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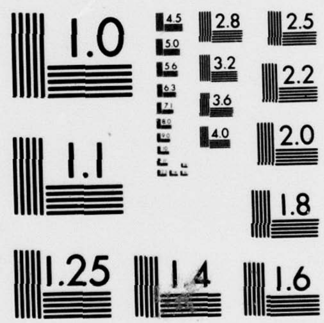


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LEVEL II

# Cleanliness Considerations for the AFGL Infrared Celestial Survey Experiments

STEPHAN D. PRICE
CHARLES V. CUNNIFF
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6 July 1978





OPTICAL PHYSICS DIVISION PROJECT 7670
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AIR FORCE SYSTEMS COMMAND, USAF

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

John Howard

Chief Scientist

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Space-borne cryogenically cooled infrared telescope systems are optically sensitive to particulate contamination along the line of sight. Methods of cleaning and handling flight instrumentation have been developed at AFGL and used on the Infrared Celestial Survey Program. These procedures are described in detail and flight results are presented.

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## Preface

Paul Harnett and Edwin LeBlanc of Wentworth Institute and C. Nealon Stark of the Air Force Geophysics Laboratory designed the payload. The attitude control system and recovery package were provided by Aerojet Liquid Rocket Company. Cleaning was done by our payload crew including David Akerstrom, Michael Mitchell, Dr. Thomas Murdock and Anthony Romanelli with the very able assistance of Wentworth Institute.

## Contents



## Illustrations

# Cleanliness Considerations for the AFGL Infrared Celestial Survey Experiments

## 1. INTRODUCTION

The Air Force Geophysics Laboratory is conducting a program of experiments to survey the sky in the 3 to 120 micron spectral region. These experiments employ cryogenically cooled telescopes flown above the atmosphere on sounding rockets. The first series of nine flights was completed in 1974. Seven of the experiments gathered celestial data in the northern hemisphere with small telescope flown from White Sands Missile Range. The instruments were modified and two flights from Woomera Test Establishment in Australia obtained southern hemisphere survey observations. Aerobee rockets were used for these experiments. The next series of measurements will extend the coverage to longer wavelengths with larger instruments and will be flown on higher performance rockets.

The success of infrared survey experiments critically depend on contamination control during the preparation of the experimental hardware for flight, and on maintaining a particle free environment during data taking. The degradation of experimental data by particulate contamination has been observed on previous Aerobee rockets flown for micrometeorite research by Farlow, Blanchard and Ferry;[1,2]

(Received for publication 5 July 1978)

1. Farlow, N.H., Blanchard, M.B., and Ferry, G.V. (1966) Journal of Geophys. Research, Space Physics 71:5689.
2. Farlow, N.H., Blanchard, M.B., and Ferry, G.V. (1968) IQSY/COSPAR Space Research VII, 557, North. Holland Publ. Co.

Blanchard, Farlow and Ferry;[3] Farlow;[4] Blanchard, Ferry and Farlow;[5] for zodiacal light studies by Tousey and Koomen,[6] and daytime celestial photography of Evans and Dunkleman.[7] Despite the careful cleaning procedures (Blanchard and Farlow[8]) particulates traceable to the instrumentation and payload were found on both the exposed and control collecting surfaces.

Particulate contamination has been detected on the payload surfaces, in the case of the Ames flights, out to a few meters for the Evans and Dunkleman[7] experiment, and to many hundreds of meters as measured by Tousey and Koomen.[6] The AFGL survey instruments span the spectral region of peak passive emission from small particles in thermal equilibrium with the near earth environment. It is possible for these sensors to detect a submillimeter diameter object at a distance of several hundred meters; thus, the requirement on contamination control.

AFGL has developed cleaning techniques which maintain control of particulates through launch of the experiment. These procedures are described in some detail. Also, as the infrared sensor's performance is a sensitive function to its side lobe response, which in turn depends critically on the quality of the optical surfaces, the techniques used to clean the optical surfaces of cryo-deposits while maintaining ultralow scattering properties is also described. Some of the flight results with respect to contamination control are presented.

## 2. INSTRUMENTATION

Figure 1 details the configuration of the payload. The radiometers used for the sky survey were doubly folded Gregorian telescopes with 16.5-cm diameter primary mirrors and cooled with supercritical helium. The focal planes contained three linear staggered arrays of eight detectors each. Each array was spectrally band limited with interference filters and aligned such that the sensor scan produced sequential measurements on a given source in each band.

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3. Blanchard, M.B., Farlow, N.H., Ferry, G.V., and Shade, H.D. (1967) Sixth Annual Technical Meeting, American Association for Contamination Control.
4. Farlow, N.H. (1968) Journal of Geophys. Research, Space Physics **73**:4363.
5. Blanchard, M.B., Ferry, G.V., and Farlow, N.H. (1968) Journal of Geophys. Research, Space Physics **73**:6343.
6. Tousey, R., and Kooman, M.J. (1967) Zodiacal Light and the Interplanetary Medium, Ed. J.L. Weinberg, NASA SP-150.
7. Evans, D.C., and Dunkleman, L. (1969) Science **164**:1391.
8. Blanchard, M.B., and Farlow, N.H. (1966) Contamination control, **5**:22.

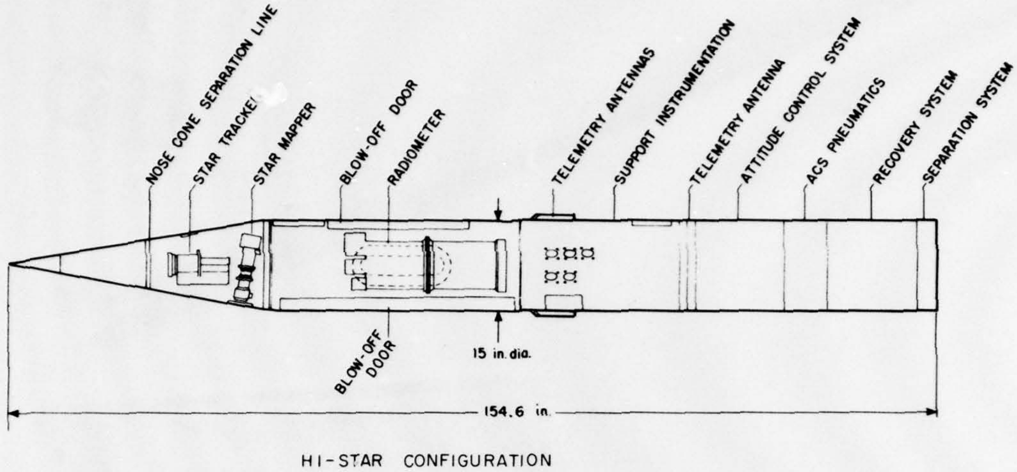


Figure 1. Payload Configuration

The seven flights in the northern hemisphere obtained observations in spectral bands centered at 4, 11 and 20 microns with an instantaneous field of view of 0.975 by 3.05 milliradians. These instruments were subsequently modified after the seventh flight by increasing the detector width to 1.4625 milliradians and substituting a 27 micron filter for the one at 4 microns. Two flights with these modified sensors obtained celestial data in the southern hemisphere. Results of the infrared Sky Survey are given by Price and Walker,[9] and Price.[10]

The payload was designed with ease of cleaning and maintenance of contamination control being of paramount importance. The basic philosophy was to design exposed surfaces to be easily cleaned, to contain particulates within uncleanable areas, to eliminate residual gas pressure within unclean areas, and to separate the clean payload from the unclean rocket vehicle. All surfaces exposed to space during data gathering were to be maintained to class 100 clean room levels. The payload cavity housing the sensor was to be cleaned as well as all external payload surfaces. These surfaces were constructed with a minimum of sharp corners and recesses.

The nose cone tip, shown in Figure 2, was built in two sections with an "O" ring seal to prevent particulate contamination after it was cleaned and mounted in place. The star mapper port is seen in Figure 3. There are two "O" ring seals

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9. Price, S.D., and Walker, R.G. (1976) AFCRL-TR-76-0208, ERP No. 576.
10. Price, S.D. (1977) AFGL-TR-77-160, ERP No. 606.

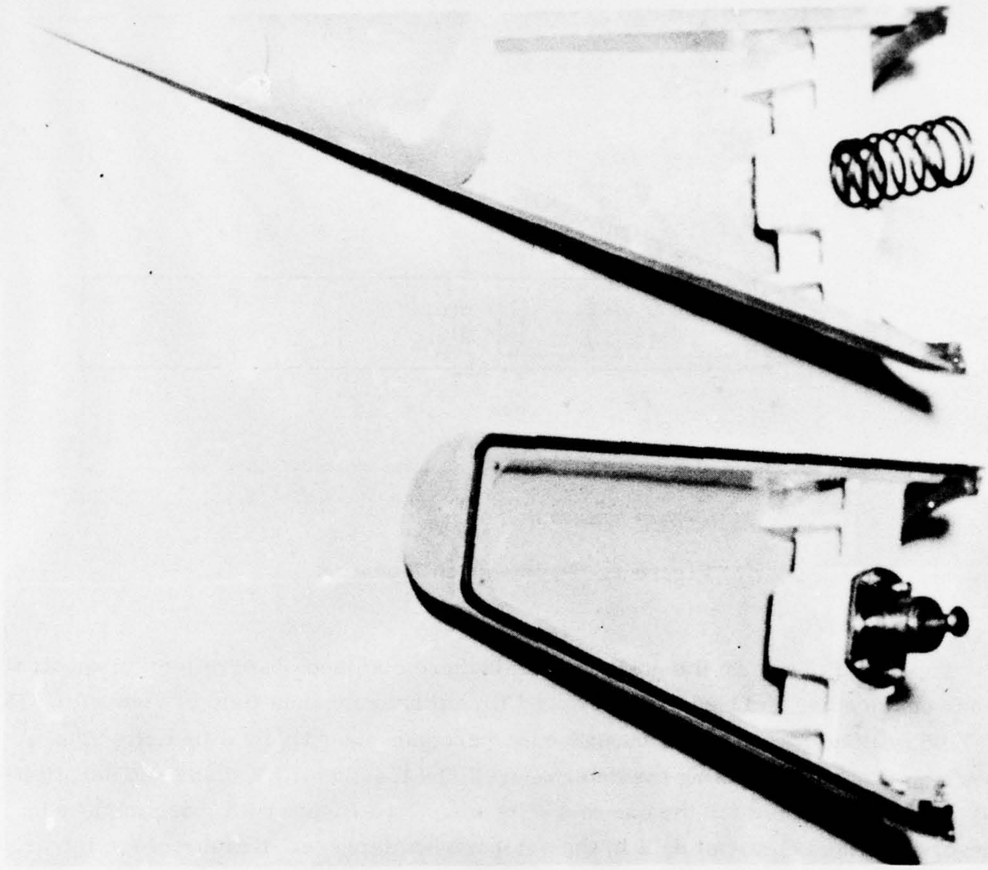

Figure 2. Ejectable Nose Cone Tip. The "O" ring seal is clearly visible

here. The outer seal is a dust seal between the rocket skin and the star mapper port, while the second is the seal on the ejectable door. Figure 4 provides a view of the radiometer section with the sensor in the stowed position. The cavity was painted with a hard, glossy epoxy paint which provided an easily cleaned, cling free surface. This cavity is separated from the star mapper-tracker section above by a solid builkhead, and from the support section below by a rubber gasket attached to the sensor cap. Servicing the sensor before launch was accomplished through an access door to the rear of the cavity above the sensor.

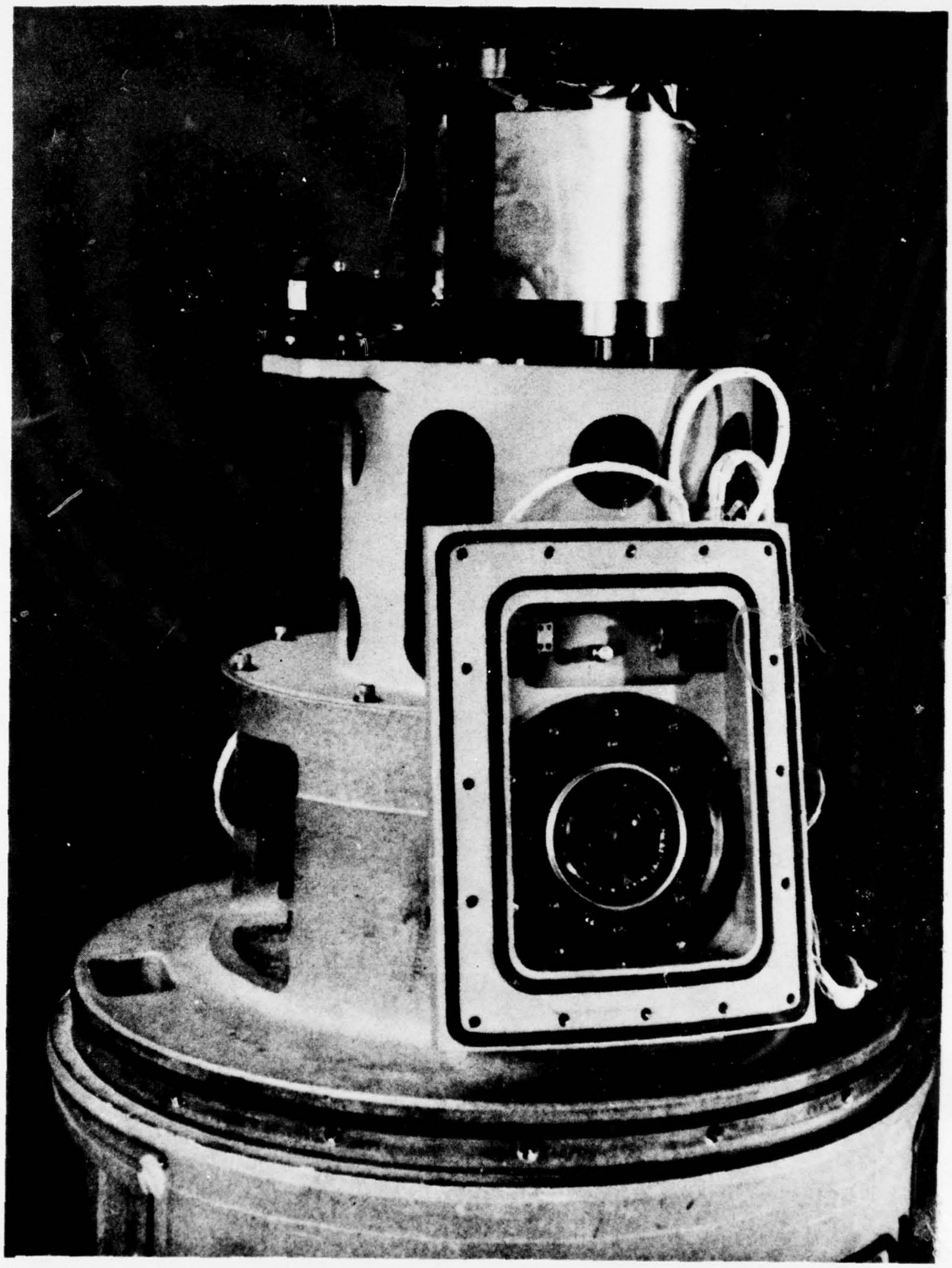

Figure 3. The Aspect Sensors for the Experiment. The star tracker is mounted on top and the star mapper port is seen facing outward. Note the double "O" ring seal around the star mapper port

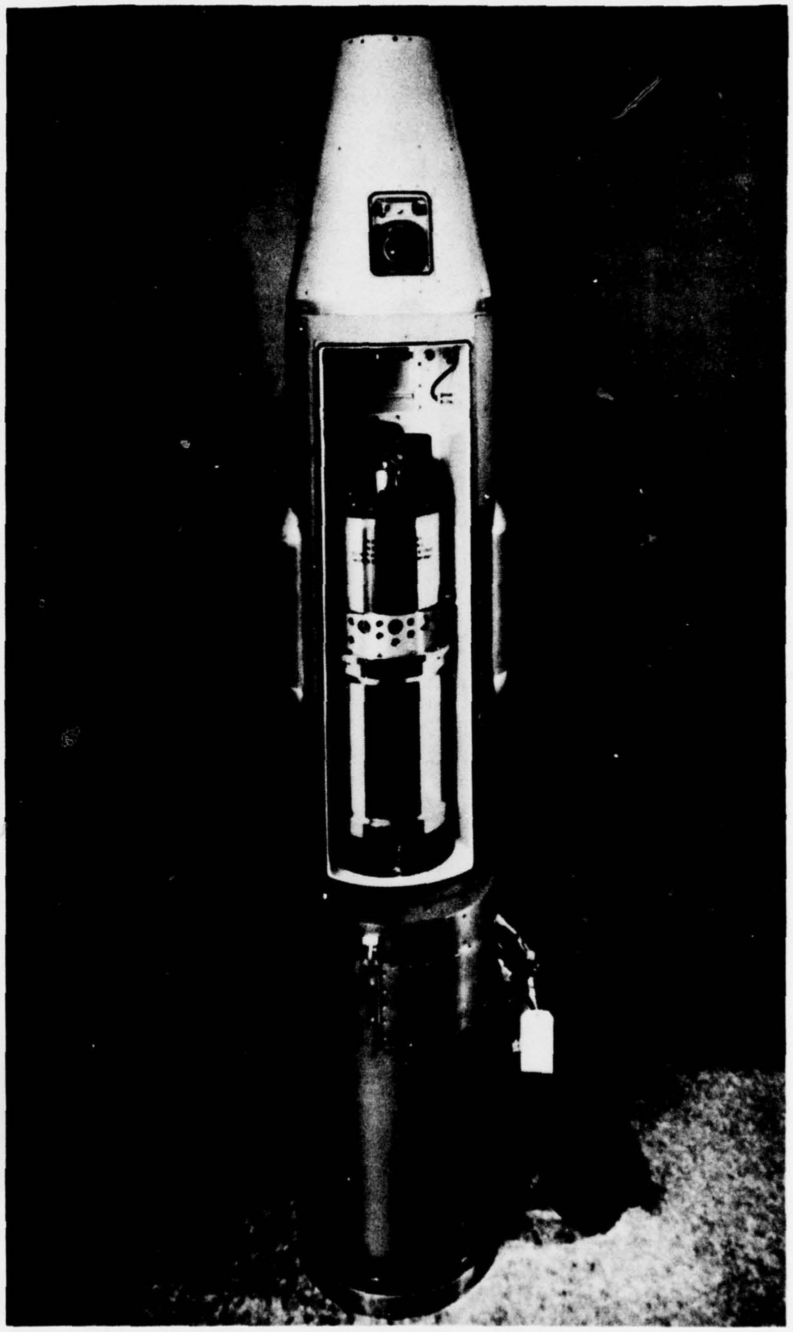

Figure 4. Payload With Sensor Blow-off Door Removed Showing the Sensor on Gimbals in the Stowed Position. The access door used in launch preparation can be seen in the top rear of the sensor payload cavity

Previous experiments on Aerobee rockets (Walker and Price[11]) found a significant residual atmospheric pressure still within the payload at the beginning of the experiment. Since this pressure could drive any particle which might remain after cleaning into the sensor field of view, it was decided to evacuate the payload during the ascent of the rocket. To do this the clean area in the sensor chamber was vented through 1.0 psi one way check valves mounted in the payload skin. The pressure setting of these valves were chosen so that they would seat just before rocket burnout. The support instrumentation and star mapper-tracker section of the payload contained too many components which were impossible to clean. These volumes were hermetically sealed from the outside and from the sensor cavity, and were vented to side panels containing the sensor gimbals through clearances in the casting as shown in Figure 5. These side panels were vented through 1 micron Millipore absolute filters, which effectively contain the particulate contamination inside the "dirty" areas.

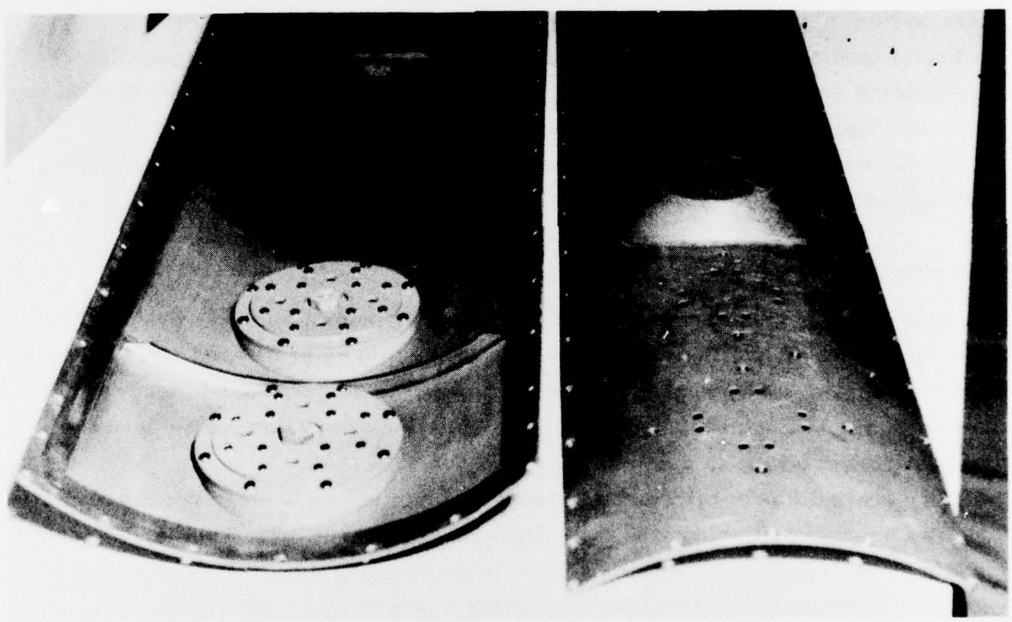

Figure 5. Payload Sensor Section Side Panels. The cylindrical mountings contain the Millipore filters

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11. Walker, R.G., and Price, S.D. (1970) Sixth Midcourse Measurements Meeting, Willow Run Laboratories, University of Michigan.

## 2.1 The Experimental Profile

After the sustainer burned out, the vehicle coasted until the aerodynamic drag was small enough to allow the attitude control system to stabilize it. The nose cone, star mapper door and the sensor section door were ejected by means of sealed bellows actuators. The centrifugal force from the 1.5 revolution per second spin of the vehicle and residual aerodynamic drag carried these items away and behind the payload. This was verified by radar track on the fourth flight. The vehicle was then despun by release of yo-yo weights and the payload separated from the sustainer by release of a Marmon clamp and springs sized to give a separation velocity of three meters per second. Note that both the payload and sustainer bulkheads of the separation system were clean.

The attitude control system captured the payload and pointed the star tracker, which was co-aligned to the rocket roll axis, to a selected star near local zenith. The sensor was deployed to a specified zenith angle and the payload rotated about the roll axis. The payload was spin balanced as part of the launch preparations in order to minimize the cross moments of inertia of this maneuver. After the payload had executed a $360^{\circ}$ roll, the sensor was stepped through an angle slightly less than the sensor field of view. Thus a contiguous sector of the sky was mapped, with each flight surveying about three steradians.

At the end of data, taking the sensor was stowed and the payload recovered. The payload and sensor were refurbished and reflown.

## 2.2 Payload Cleaning Procedures

Disassembly and assembly of the sensor took place in a clean work station. This station provided a laminar flow of 100 ft per minute of filtered air. Filtering the air was a two step process. Pre-filters provide 60 percent efficiency while the final stage, using absolute filters, was 99.97 percent effective on particles exceeding 0.3 microns in diameter.

The payload was serviced and cleaned in a laminar flow clean room which also used two stages of filtering, the pre-filter and absolute filter. This facility provided a class 100 clean room atmosphere in the working area. Preparing the clean room for use required a complete vacuuming followed by scrubbing with soap and water, then rinsing and finally at least a two day purge prior to any clean room activity. The clean room conditions were monitored by a particle counter which provided a continuous sampling of the air to detect particles larger than 0.5 microns in diameter. Digital counts of the particles were provided by a visual display and an audio alarm alerted the clean room users to violation of acceptable cleanliness standards. If a breakdown in the cleanliness occurred, all work stopped and all components which had been cleaned were covered. Remedial action is taken and when the required cleanliness was once again obtained, operations were resumed.

The clean room clothing consisted of nylon frocks, boots, hats and gloves. Clean clothing of other material were found to give an excessive amount of lint. An ultrasonic cleaner with a Freon TF grade purging agent was used to clean all the small parts which included the separable nose cone, screws, washers and all the tools used in the clean room. An aerosol can of freon, or clean air, with a 0.5 micron filter was used to dislodge particles trapped in inaccessible areas. An ultraviolet light was used to see lint, dust and other fluorescent material. All particulate contamination, including the fluorescent materials, were cleaned from all the surfaces to be exposed to space with a vacuum cleaner and stiff bristle brush.

The payload was mounted horizontally on a cradle with rollers which permitted it to be rotated giving easy access to all sections to be cleaned. The nose cone end was positioned close to the filter banks of the 20 ft clean room and canted slightly. Cleaning began at the nose cone end with the previously cleaned areas and that being cleaned always being positioned between the filters and the personnel doing the preparation. This is important to prevent recontamination of the clean areas by personnel.

A clean, lint free nylon cloth was used to apply liberal amounts of clean Freon over the skin of the payload and around the star tracker and mounting area. The star tracker mounting area was then vacuumed and inspected with the aid of the ultraviolet lamp. The star tracker lens was cleaned with standard lens paper and cleaner.

The separable nose cone, which was cleaned separately, was assembled and attached to the payload. The skin was again flushed with Freon to below the star mapper detent and vacuumed. The star mapper door, which had been cleaned separately in the ultrasonic bath, was mounted. Then an ultraclean polyethylene anti-static bag 36 in. in circumference was pulled over the nose of the payload down to the star mapper door. This bag, which eventually encased the entire payload, effectively isolated the upper clean portion from contamination.

The sensor and payload sensor cavity were cleaned next. Once again the payload skin was washed with Freon and vacuumed from below the bag to below the payload cavity. The sensor exterior, casting cavity and all the cables and connectors were then cleaned in preparation for opening the sensor. The sensor cap was lowered, the telescope was deployed and the sensor was cleaned with the vacuum. Since the sensor was assembled on a clean bench, particles were rarely seen. Occasionally, however, the multilayer insulation did flake.

On completion of the cleaning, the sensor was stowed and the cap raised into place. The equipment used to service the sensor in the launch tower was cleaned and attached to the sensor through a temporary split access door. This hardware consisted of the Richards valve actuator which controlled the sensor vacuum port,

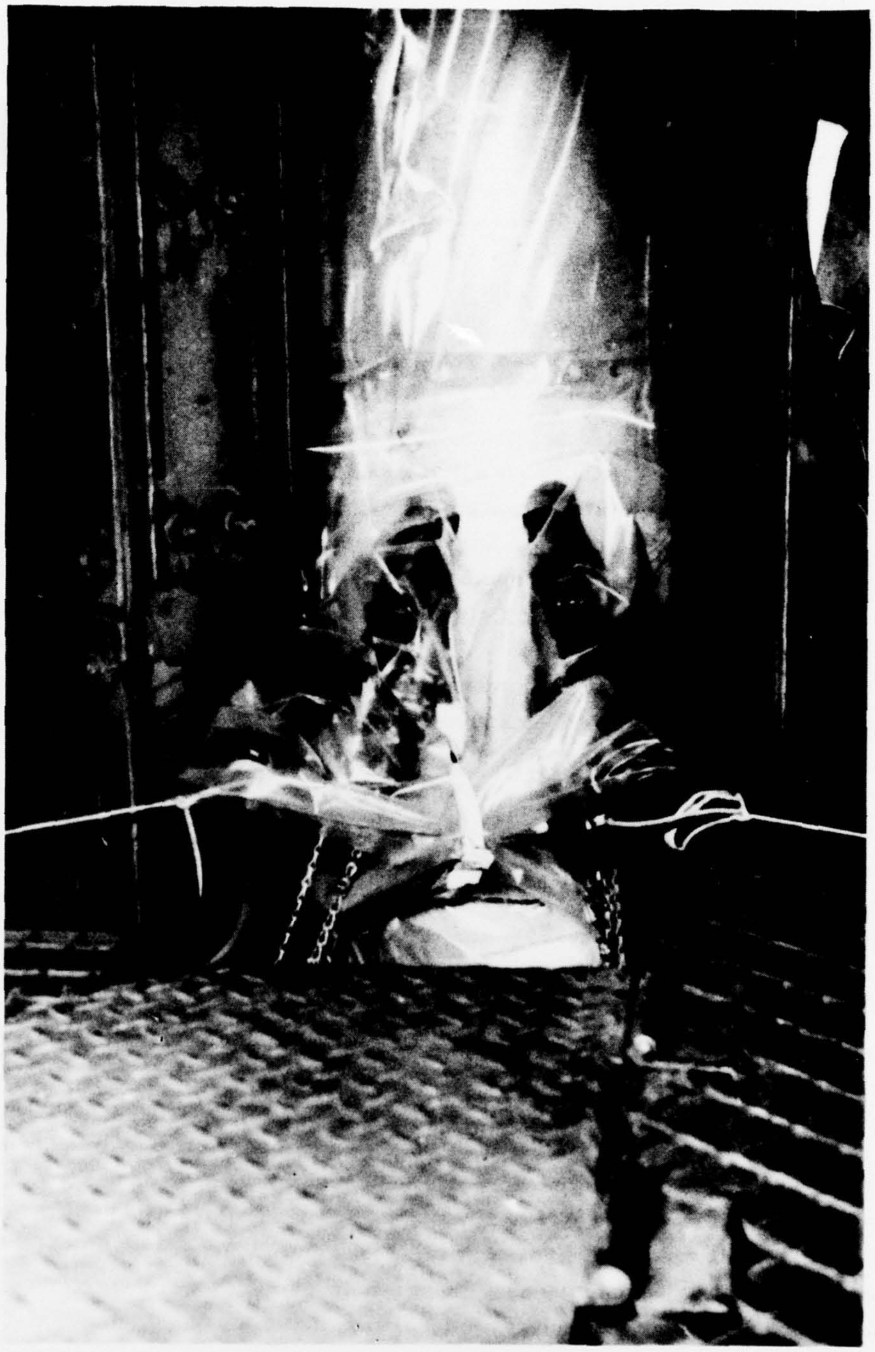

Figure 6. Umbilical Attached to the Payload Through Sleeves

the liquid helium fill line and overboard helium exhaust lines. The cavity and contents were inspected under ultraviolet light, recleaned, then isolated by attaching the clean blow-off doors. The skin was again purged and cleaned and the polyethylene bag moved along the payload to below the sensor door. The remainder of the payload, from the bottom of the sensor doors to the bottom of the recovery section, was systematically cleaned with Freon, black light and vacuum cleaner. Each section was isolated after cleaning by moving the clean bag along the skin.

The payload, encased in the clean bag, was serviced during preparations in the launch tower through polyethylene sleeves attached to the bag at strategic locations, such as the temporary service door for the sensor. Here, in addition to the vacuum and liquid helium lines a clean sleeve and bag was inserted in the clean room. The sleeve provided access to this area in the tower while minimizing the possibility of contaminating other areas of the payload. The bag contained the flight door as well as other equipment to prepare the payload for the final "buttoning up" before launch. Other sleeves provided access to the experiment timers, the flight battery door, umbilical connector section and attitude control system battery door. A second clean bag stretched over the entire payload protected the entire package during transportation, mating with the sustainer and placing the vehicle in the launch tower. The connector ends of all umbilical cables are cleaned with Freon, vacuumed with the aid of a black light and double bagged in order to protect the payload from contamination during mating on the tower and connected through a sleeve as seen in Figure 6.

All the bagging material remained on the payload until seventy-five minutes before launch. At that time it was washed down with Freon and pealed off to prevent transfer of particulate contamination to the payload skin. The cleaning procedure leaves the payload grease free, so any dust that settles on the payload during the hour before launch that it is exposed to the environment is scrubbed off during the flight through the atmosphere. At White Sands Missile Range the launch tower was enclosed in an air conditioned building but at Woomera, Australia the vehicle was launched from a rail.

## 3. RESULTS

Aerodynamic forces heated the skin of the rocket to between 390 and 440$^{\circ}$K during ascent. However, a small particle from the surface of the payload would quickly thermalize to the radiative environment of near earth and stabilize at a temperature of about 270 to 285$^{\circ}$K. The distance, R, to which a particle of diameter, a, can be seen is given by

$$R = \left( \frac{H_a \pi a^2}{H_L} \right)^{1/2} \tag{1}$$

where $H_a$ is the blackbody in band flux from the particle and $H_L$ is the limiting flux for the sensor. Price and Walker[9] estimate that the AFGL Infrared Catalog is statistically complete at 11 microns to $m(11) \simeq -1.1$ or $H_L(11) \simeq 2.5 \times 10^{-16}$ W $cm^{-2}$ $\mu m^{-1}$. Since $H_a$ (280°K) is about $7.5 \times 10^{-4}$, we have from Eq. (1)

$$R \simeq 3 \times 10^6 a \quad .$$

This means, for example, that a 10-micron diameter particle would have been seen out to a distance of 30 m.

However, this assumes that all the collected energy falls onto a detecting element and such is not the case for near field particles. For out of focus images, the energy is uniformly spread over an area of

$$\frac{\pi}{4} \frac{FL^2 D^2}{R^2}$$

for an unobscured aperture of diameter, D, and focal length FL. For the Gregorian telescopes used in the AFGL survey, this out of focus image took the shape of an annulus which preserved the ratio of the diameter of the primary to the diameter of the central obscuration. The energy onto a given detector of area $A_d$ from a near field particle is given by

$$\frac{A_d}{\frac{\pi}{4} \frac{FL^2 D^2}{R^2} \text{(obscuration factor)}} \quad . \tag{2}$$

This energy then is directly proportional to the square of the distance. This means that out to critical distance, about 75 m in the case of the AFGL telescopes, the energy on a detector is independent of the distance of the particle and is a function of its size only. Thus, with these parameters, a 25 micron diameter or larger particle would have been seen out to 75 m. At larger distances the size of the particle scales according to Eq. (1).

No discernable particulate contamination greater than 25 microns in diameter was detected on eight of the nine flights within the one million cubic meters surrounding the payload and swept out by the sensor on each flight. The contamination

on one flight appeared to be traceable to a faulty door release rather than inadequate cleaning procedures.

The statement about the degree of cleanliness on these experiments can be made with certainty as near field particulates give rise to very characteristic spatial and spectral signatures. An object very close to the sensor, within a few meters, would appear as an extended source many tens of degrees across. As the particles move away from the telescope, the apparent angular extent is reduced and a characteristic double hump appears as the detector scans across the annulus of the out of focus image. At about 150 m away, the particle would appear as a single extended object the size of a detector width. Although these latter signatures would be indistinguishable from real background sources, it is difficult to see how particles could be observed in the far field without seeing any in the near field.

These signatures are shown clearly in Figures 7 and 8. Figure 7 is a scan which shows the signature of a real stellar source. The traces are arranged in groups of three channels at the same elevation and the groups are ordered in ascending elevation from bottom to top. The offsets of the colors from the centerline of the sensor produce the staggered detections. The first color to see the source is the 11 micron band, followed by the 4 micron band and finally the 20. As the in band sensitivity is roughly the same in each color, a normal star produces the largest deflection at 4 microns, next largest at 11 and the smallest at 20 microns, exactly as shown in Figure 7.

In contrast to this, Figure 8 shows the signatures of near field particles characterized by the double deflection due to the out of focus annulus. The peaks are separated by about a half degree and the particle in the center spans the full 1.2 degree field of view of the sensor. Note the absence of a 4.2 micron signature which attests to the cool temperature of the source.

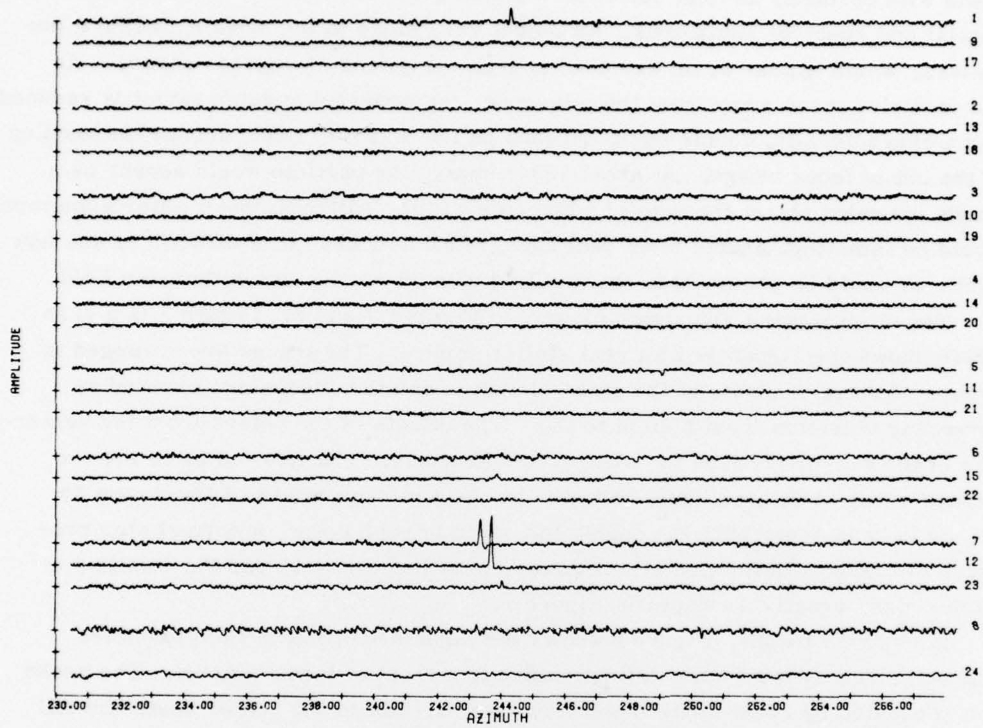


Figure 7. A Portion of the Raw Data Output as the Sensor Scans Across a Star Which is Observable on Channels 7, 12, and 23, the Next to the Bottom Triad of Channels. No provision has been made for the detector offsets in the focal plane so the 11 micron (channel 7) signal occurs first followed by the 4.2 micron channel (12), then the 19.5 micron channel (23). Channel 16 has been deleted from consideration due to excess noise

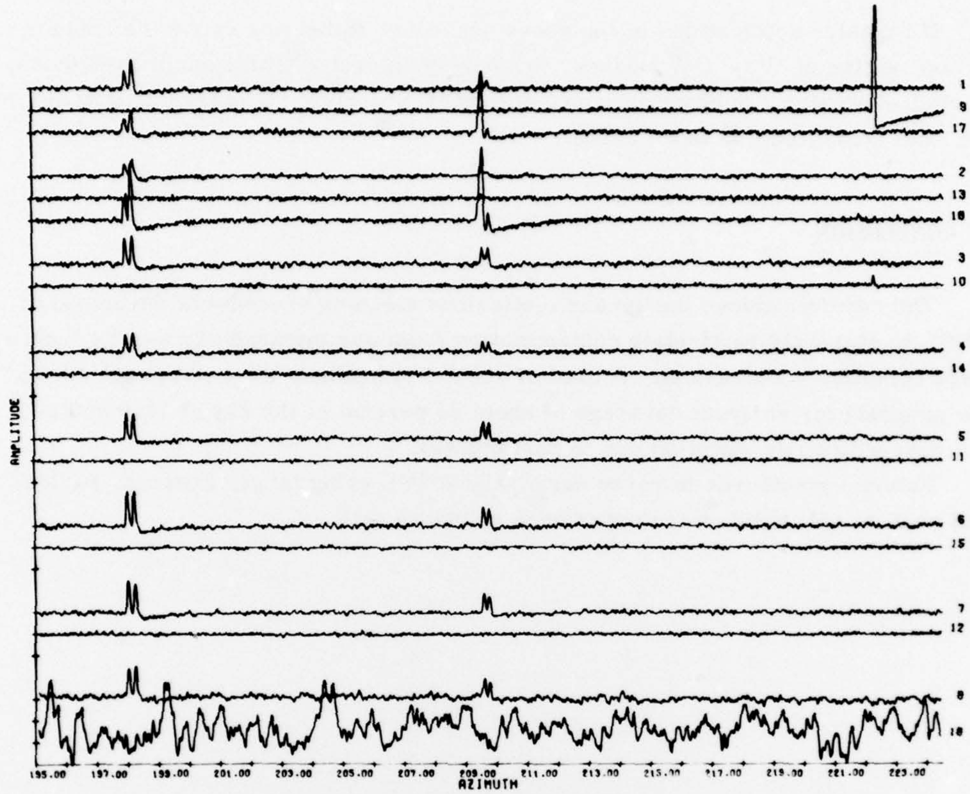


Figure 8. Detection of Near Field Particulates Which are Characterized by the Double-Humped Signature as the Two Sides of the Out-of-Focus Annulus are Scanned; Also the 4-micron Detection is Absent while the 11 and 20 micron Deflection are About Equal. The latter effect is characteristic of a 300°K temperature. No data was obtained on the bottom six 20 micron channels on this flight

## 4. OPTICAL CLEANING PROCEDURE

The telescope primary and secondary mirrors used for the southern hemisphere flights were superpolished, canogen coated, beryllium. Special cleaning techniques were developed to prevent degradation of the low scattering properties of the mirrors. Contact with the mirror surface was restricted solely to liquids. The first application was a spray of acetone to remove surface contaminants such as vacuum grease and the like. A spray of 99.9 percent pure ethyl alcohol removed the residual acetone and dissolved grease and oil. The alcohol was in turn removed by a bath of distilled water and non-ionic soap or very mild dishwashing detergent. Finally, flooding the mirrors with distilled water removed the residual soap solution. The process was repeated until visual inspection indicated that all deposition was removed.

If repeated applications of the above procedure failed to remove the contamination, strips of "Kay dry" tissues, thoroughly saturated with each of the liquids, were drawn without surface pressure across the mirrors. The technique removed the final contamination in all cases.

## 5. CONCLUSION

The careful payload design and meticulous cleaning procedures developed at AFGL to eliminate particulate contamination from our infrared sky survey flights were completely successful. A total of about 9 steradians were swept out during the program for an areal coverage of about 90 percent of the sky at 11.0 and 20 microns with no degradation due to particulates.

Future rocketborne infrared surveys at AFGL using larger sensors, payloads and rockets will build on the experience gained to date.

## References


1. Farlow, N.H., Blanchard, M.B., and Ferry, G.V. (1966) Journal of Geophys. Research, Space Physics 71:5689.
2. Farlow, N.H., Blanchard, M.B., and Ferry, G.V. (1968) IQSY/COSPAR Space Research VII, 557, North. Holland Publ. Co.
3. Blanchard, M.B., Farlow, N.H., Ferry, G.V., and Shade, H.D. (1967) Sixth Annual Technical Meeting, American Association for Contamination Control.
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5. Blanchard, M.B., Ferry, G.V., and Farlow, N.H. (1968) Journal of Geophys. Research, Space Physics 73:6343.
6. Tousey, R., and Kooman, M.J. (1967) Zodiacal Light and the Interplanetary Medium, Ed. J.L. Weinberg, NASA SP-150.
7. Evans, D.C., and Dunkleman, L. (1969) Science 164:1391.
8. Blanchard, M.B., and Farlow, N.H. (1966) Contamination control, 5:22.
9. Price, S.D., and Walker, R.G. (1976) AFCRL-TR-76-0208, ERP No. 576.
10. Price, S.D. (1977) AFGL-TR-77-160, ERP No. 606.
11. Walker, R.G., and Price, S.D. (1970) Sixth Midcourse Measurements Meeting, Willow Run Laboratories, University of Michigan.